ABRASION OF BEACH SAND

TECHNICAL MEMORANDUM NO. 2

BEACH EROSION BOARD
OFFICE OF THE CHIEF OF ENGINEERS
WASHINGTON, D. C.
FEBRUARY 1942

WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY

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WAR DEPARTMENT
Office of the Chief of Engineers
Beach Erosion Board
Washington

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SYLLABUS

On sandy beaches the loss of material ascribable to abrasion and the resultant recession of the shoreline, occur at rates so low as to be of no practical importance in shore protection problems.

PURPOSE OF STUDY

The loss of beach material ascribable to abrasion is frequently referred to in connection with the observed recession of shorelines on sandy coasts. Beach drifting material is subject to abrasion, or wear, and consequent loss as a result of its movement by waves and currents. For shore protection work the importance of the subject depends upon the rate of loss due to abrasion as compared with the rate of loss or gain of beach material by the action of other forces. The purpose of this study is to examine into the rate of loss by abrasion with a view to ascertaining its importance in beach erosion processes.

TRANSPORTATION PHENOMENA

The movement of beach material by waves and currents results in both sorting and abrasion. Each of these phenomena will be discussed briefly.

a. <u>SORTING</u>. - It is well known that hydraulic transportation tends to sort material carried in suspension according to its settling velocity. This fundamental property which controls the hydrodynamic behavior of a particle depends upon the size, shape, and density of the particle, and upon the physical and dynamic properties of the carrying fluid. During transportation, variations in the velocity and in the scale and intensity of turbulence of the fluid must be reflected by dynamic responses of the transported particles in terms of their size, shape and density. If there is a progressive variation in transportation conditions along a beach there must be a related variation in size, shape and density of the deposits.

For materials ordinarily encountered along the beaches of the United States variations in size are of common occurrence and variations in shape of lesser occurrence. Variations in density are largely offset by variations in size; for instance, small grains of high density material such as magnetite are frequently found mingled with large grains of lower density quartz.

In the case of beach sands, the sorting may be classified as "local," involving the arrangement of particles at a particular locality, or "progressive," involving an assortment of particles in the direction of transportation.

Local sorting results from the plunge, uprush and backwash of the incident waves or the effect of winds above the water line. The sorting process is confined to a limited area. The most obvious result of local hydraulic sorting is the concentration of relatively coarse material in the vicinity of the plunge point, bordered by finer material both shoreward and seaward of that zone. The concentration of magnetite, or other high density materials, frequently noted on the surface of sand beaches, is attributed to local sorting.

Progressive sorting is due to the disturbance of beach material by the plunge of the wave and the other phenomena responsible for local sorting, combined with alongshore currents, either wave or wind induced, which move temporarily suspended sand in the direction of the current. The longer a particle remains in suspension after having been disturbed the greater its movement from its initial position before being redeposited. A frequently cited result of progressive sorting is the decrease in size of beach drifting material as the distance from its source increases.

This characteristic of progressive sorting is not, however, definitely proven by observations in the field. Certain studies made on Cape Cod by Schalk indicate an increase in size of material as distance from the probable source increases. A study of sand movement along the south shore of Long Island made by the Board indicates at least a partial agreement with the theoretical result; while MacCarthy concludes that along a relatively straight coast the average fineness of the sands increases regularly in the direction of the current, and that the diminution of size is a linear function of the distance traveled. It may be stated that well-defined examples of progressive sorting are difficult to find in nature. The number of variables involved in the process and their complex relationship probably account for many of the variations from theoretically predicted behavior noted in field studies. It has been suggested, particularly by geologists, that the relative effectsof sorting and abrasion can probably be determined only by separation of the two phenomena in the laboratory.

b. ABRASION. - Abrasion reduces grain size and changes grain shape by the alteration of individual particles subjected to wear by rubbing and grinding, and by the fracture of individual particles through impact or chipping. Particles composed of soluble or chemically active materials are also subject to alteration by reason of solution and chemical action. These latter materials are not commonly found on beaches in the United States and a discussion of the effects of solution or chemical action will be omitted from this paper.

The product of abrasion due to rubbing is an exceedingly fine powder that is probably carried away in suspension whenever exposed to the action of transporting forces. Generally no deposits of this material are found on the surface of the berms and foreshores of beaches, or in the zones of shallow water and moderate turbulence offshore, but they are frequently found below the surface of such deposits. This condition would indicate that the sorting process is relatively inefficient insofar as subsurface materials in a zone of slight disturbance are concerned.

The particles which have been subjected to abrasion by rubbing have individually lost part of their volume as a result of the abrasive process. However, it should be noted that the effect of rubbing action is principally to round sharp corners and to reduce angular protuberances. The percentage of the total volume of particle lost in such a transformation is small. Plate I shows the characteristic shapes of grains classed from angular to well-rounded. It will be seen that angular grains are usually many faceted, and as noted above, the rubbing process involves only the removal of small amounts of material to arrive at a somewhat rounded surface. It is observed that the general shape characteristic of particles subjected to rubbing is retained, with little change, if any, in the grain mean diameter.

The products of chipping and fracture consist of angular particles of reduced size, frequently of a flaky rather than rounded or cubical form. For a rock particle to be chipped or fractured a relatively severe blow is required and it is not believed that particles in the size range of ordinary beach sand, from 0.2 mm. to 2 mm., are subject to such action in any considerable degree. However, in the case of pebble beaches which are fairly common along the coastlines of the United States, the phenomena of reduction in size by reason of fracture or chipping may be of considerable impor-

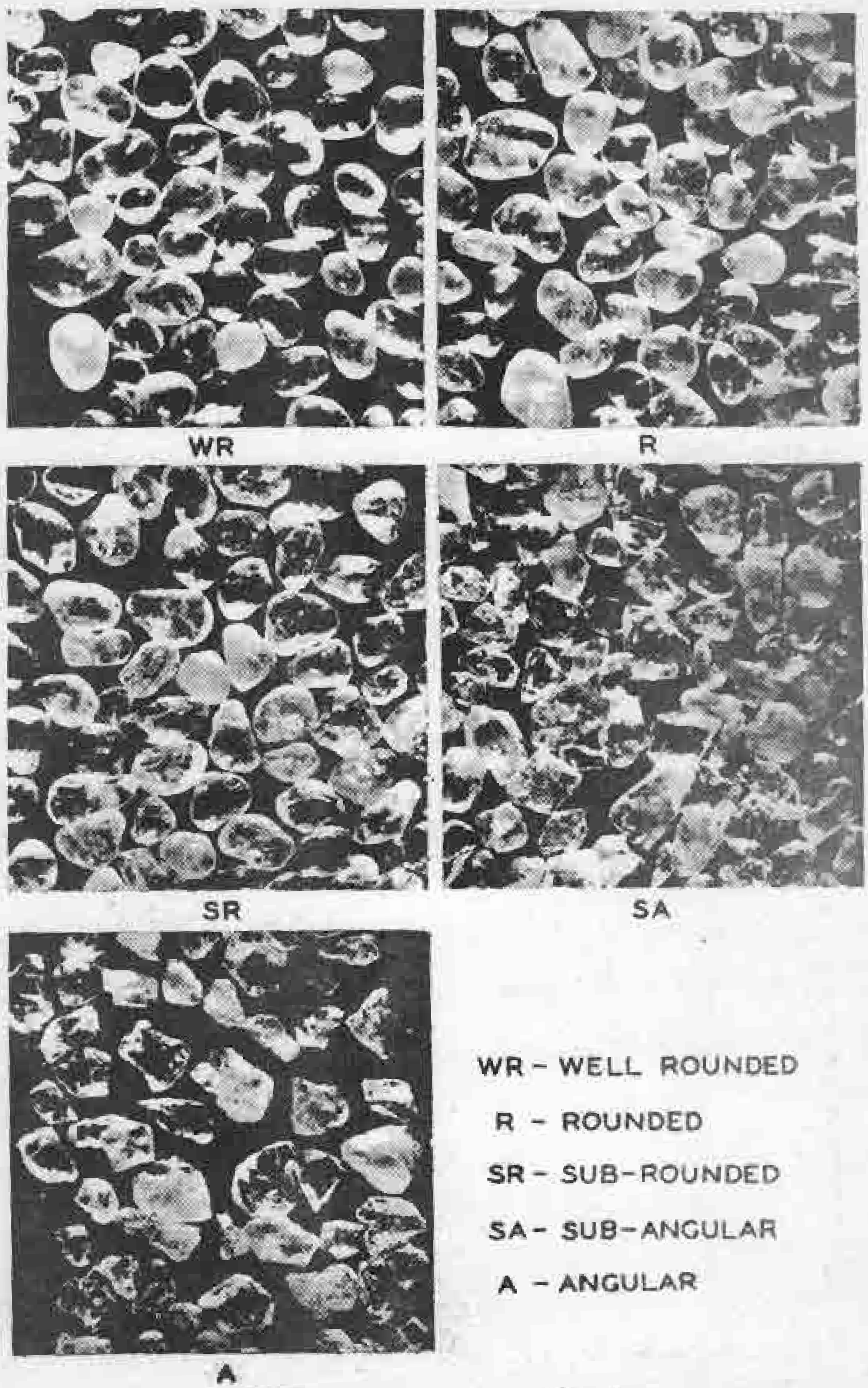

PLATE I - Sand classification chart prepared by Dr. R. Russell, Louisiana State University tance.

Experiments by Marshall have shown that no chipping was noted for sand sizes or for gravels of less than about 12 mm. in diameter. Marshall's tests included a study of material from New Zealand beaches and from river-borne debris, as well as studies made in a Deval rotating-drum machine. It was likewise found that a mixture of sand with gravel, cobbles, or larger fragments resulted in a very rapid reduction in the percentage of sand present by reason of grinding action.

It may be expected that appreciable changes in individual particles may result from chipping or fracture, on beaches composed of coarse gravel or shingle. The products of chipping and fracture, which ultimately may be in the sand size range, will be subject to local and progressive sorting by hydraulic forces. It is believed that in this case relatively little material may be ground so fine as to be subject to transportation in suspension for long distances and to consequent wastage as far as the beaches are concerned. It is concluded that for pebble beaches at least, there may be an appreciable loss of weight of individual particles by reason of abrasive action, but that such loss may not represent a loss from the beach unless the resulting material is so fine as to be subject to removal by the transporting process. It is quite probable that the loss of weight of individual particles in this case may not be translated directly into a corresponding loss of volume from the beach.

BEACH CONDITIONS

In the course of its studies of beach erosion at various localities, the Board has collected and analyzed samples of beach material representative of the material found on the shorelines of the United States. A study of the analyses of these samples indicates that material smaller than about 0.07 mm. is rarely found on the surface of beaches, although sub-surface samples frequently contain small percentages (up to about 0.5%) of such material.

In view of the extent of the sampling operations it may be concluded that material smaller than about 0.07 mm. probably cannot remain on a beach when exposed to littoral forces, and is carried away in suspension. It seems reasonable that if the size of the products of abrasion approaches about 0.07 mm. or less, then such products will ultimately be lost from the beach. This loss must be the only loss ascribable to abrasion, inasmuch as larger material, though it may be transported on-, off-, or alongshore, ordinarily may not be carried in suspension to a position from which it cannot regain the beach.

EXPERIMENTAL STUDIES

Perhaps the earliest experimental work on the effects of abrasion was by Daubrée, reported in "Etudes Synthétiques de Géologie Experimentale" in 1879. Daubrée concluded in part that:

a. "The rate of wear is more rapid for large than for small particles.

b. "The rate of wear is a function of the rigor of the process.

c. "Wear may be due either to abrasion or to breakage; the effects of the two are not the same.

d. "The product of abrasion is almost entirely mud rather than sand."

Anderson reports the results of abrasion tests on beach sands from Nahant, Massachusetts, and Huntington Beach, California; and on dune sands from the Rio Grande and Colorado Rivers. A mechanical agitator was used that "simulated wave-tossed sand in the churning water of a beach during a storm, or the agitation of the wind-carried sand during a dust storm." The results show that practically no material finer than 0.074 mm. diameter was produced during test periods of as long as 370 hours. A total loss of material of about 1 per cent, including the losses in handling, was observed. The conclusions reached by Anderson were:

a. "The rounding of sand grains by mechanical wear is an exceedingly slow process. The wear has been much less than was expected.

b. "It does not appear likely that sand grains in a single journey from the central part of a continent to the sea would experience sufficient wear to become rounded. In order to become rounded by either wind or water, sand grains must probably make several such journeys through more than one cycle of erosion, transportation and deposition.

c. "It follows that sand grains approaching spherical shape may be of considerable age.

d. ".... The gathering grounds for rounded grains are the beach and dune areas."

Marshall's tests on the rate of wear of gravel and of sand show that the loss of weight in samples of feldspar of 44.4 mm. average diameter and 4.7 mm. average diameter in 24 hours mechanical agitation in a Deval machine was respectively 4 per cent and about 0.3 per cent. A second test showed the loss of weight of 2.7 mm. average diameter grains and 0.27 mm. average diameter grains, under the same conditions, to be respectively about 0.2 per cent and 0.013 per cent. With reference to these latter figures Marshall notes that the loss by abrasion was somewhat over-estimated by reason of the technique employed. Note that the hardness of feldspar is 6, that of quartz is 7.

These experiments led to the following conclusions:

> a. "The general occurrence of sand on beaches the world over indicates clearly that this material is always being supplied to the coasts in large quantity; but the frequency and permanence of sand beaches in localities far distant from any source of supply indicate as clearly that sand is being reduced in grade very slowly by wave action."
>
> b. "Abrasion (rubbing) takes place with extreme slowness when a beach is composed of pebbles finer than 3.4 mm. in diameter."
>
> c. "The absence of the finest grade of sand (less than 0.07 mm.) is ascribed to flotation (suspension)."

Daubrée's earlier finding that mud, rather than sand, is the main product of abrasion was substantiated by Marshall.

Wentworth studied coal fragments about 40 mm. in diameter from the wreck of the AMARANTH on Jarvis Island, which had been subjected to wave action on the beach for eleven years. His measurements indicated that the rate of wear of the fragments was about 0.04 per cent by weight per day, or about 12 per cent per year. He notes that in places the coal forms as much as 25 per cent of the beach gravel and lies chiefly on the upper beach, owing to the lesser specific gravity of the coal than of the calcareous debris. The associated gravel ranges mainly from a diameter of 32 mm. down to the size of coarse sand, and consists of coral fragments, pieces of shell of the giant clam, (and other shells). Wentworth gives the size of the coal particles as 40 mm. Applying the ratios of rate of wear determined by Marshall to the result given, we find the rate of wear of coal particles having an average diameter of 0.40 mm. would be about 0.0004 per cent by weight per day. No data were obtained as to the proportion of this material lost from the beach by transportation in suspension.

These figures indicate a rapid loss of coal due to abrasion. However, the fact that the coal was mixed with a much harder beach material may have increased the rate of loss even though the natural sands present were smaller than the coal fragments. Also, anthracite with a hardness of only about 2 could be expected to wear much more rapidly than ordinary beach material, such as quartz (hardness 7) and feldspar (hardness 6).

The Beach Erosion Board conducted experiments in a wave tank to determine the rate of wear and loss of weight of anthracite coal submitted to wave action. The coal was screened through ½-inch and ¼-inch mesh sieves and the material retained on the ¼-inch mesh sieve selected for test. After thorough washing the coal was placed in the wave tank on a slope of 1 to 5. On this slope a region equal in length to one wave length of the waves employed was isolated from the remaining coal by low barriers placed flush with the surface of the beach. The purpose of this arrangement was to concentrate the wave action on a few particles, thus intensifying the rate of wear. The water level was adjusted and maintained at an elevation such that the plunge point of the waves was located about one-third of a wave length up the slope from the lower partition.

The wave generator was adjusted to produce the wave of maximum energy possible with the equipment. The wave characteristics were: height = 0.24 ft., length = 8.25 ft., height/length = 0.029, corresponding to storm waves in nature, period = 1.61 sec.; and wave energy available per hour = 8,342 ft.-lbs. per linear foot of beach.

The test was conducted in a closed tank so that all of the products of wave action on the coal were retained. Samples of the water were taken to be analyzed for suspended material content; and samples of the coal from five sections of the beach, three in the isolated section, and two down slope, were taken for analysis of change in shape.

The test was run for 224 hours. At that time the material in suspension in the water, representing approximately the amount of material which had been lost from the beach, was 0.065 per cent of the total weight of coal. The rate of loss was about 0.007 per cent per day for the size range studied, (about 12.6 mm. to 6.3 mm.).

Analysis of the change in shape of the coal grains showed no measurable change with the measuring technique employed. Using Wadell's method for measuring and expressing the shapes of grains, the ratios of sphericity were: initial = 0.749, final = 0.746, and the ratios of roundness were: initial = 0.298, final = 0.314. It was noted, however, that some chipping of the coal particles had taken place, as evidenced by the occurrence of small fragments in some of the samples used for shape determinations.

Schoklitsch has verified Sternberg's equation for loss of weight due to abrasion in bed load transportation. The tests are comparable to those of Marshall and Anderson since mechanical agitators of similar design were used by each of the investigators. Although numerical values derived from mechanical agitation tests are probably not directly applicable to beach processes, it is believed that the error involved is not great.

Sternberg's equation is: $P = P_0 e^{-cs}$

where P = weight of particle after abrasion

P_0 = initial weight of particle

s = distance traveled by particle

c = specific abrasion (loss of weight per unit weight per unit distance). It is a function of the velocity of transportation, the characters of the particle materials and surrounding materials, and the shape of the particles.

e = base of natural logarithms.

Schoklitsch's tests give a value of $c = 0.015$ for quartz, when the transporting velocity is 0.8 m/s and the surrounding material is flint in grains about 35 mm. in diameter.

Among Schoklitsch's conclusions is the statement, "Wear by impact (breakage) is more rapid than wear by abrasion; in some instances more than ten times as great."

Krumbein confirms the work of Sternberg and Schoklitsch insofar as he concludes that the law for decrease in particle size due to abrasion is a negative exponential function of the distance traveled and the nature of the particle.

CONCLUSIONS

It is concluded that the product of abrasion of beach material is smaller than about 0.07 mm. particle diameter; that such particles are subject to removal and loss from the beach by transportation; that the magnitude of such loss cannot be stated exactly but is probably a function of the mobility of the beach; and that abrasion of particles in the sand size range proceeds very slowly.

It is therefore further concluded that the loss of beach material ascribable to abrasion is of very minor importance as compared to the losses and gains of material ascribable to littoral movement.

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